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EXPERIMENTAL TRANSONIC STEADY STATE AND UNSTEADY PRESSURE MEASUREMENTS ON A SUPERCRITICAL WING DURING FLUTTER AND FORCED DISCRETE FREQUENCY OSCILLATIONS

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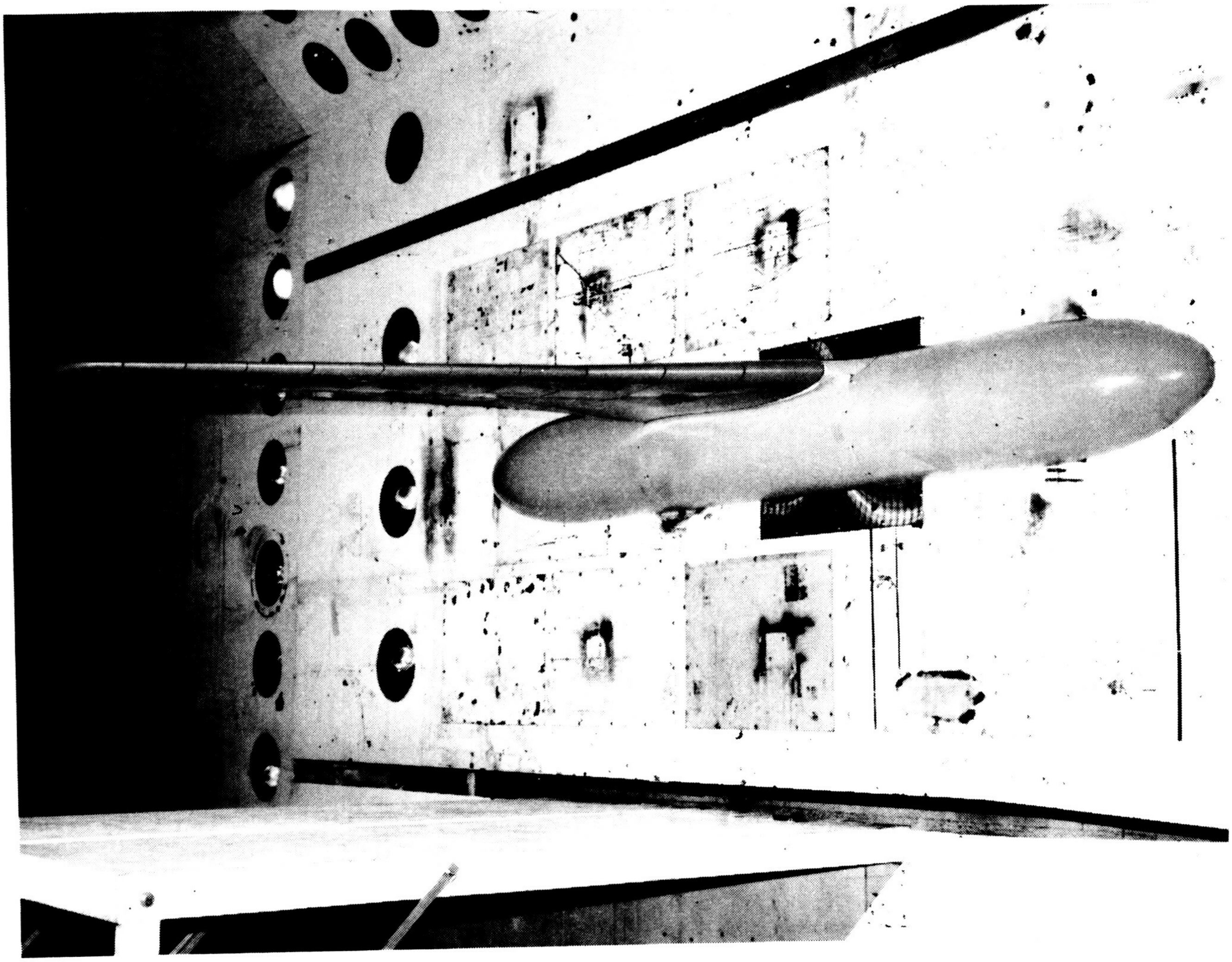
PICTURE OF MODEL IN WIND TUNNEL

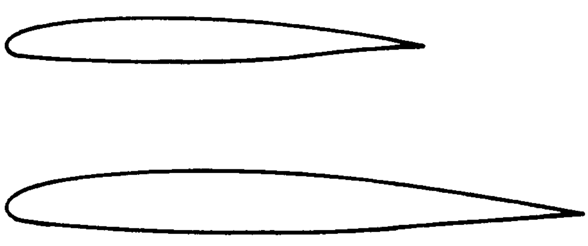
A joint Langley-Lockheed wind tunnel test was undertaken involving this model. The motivation for this test is explained in the figures to come.

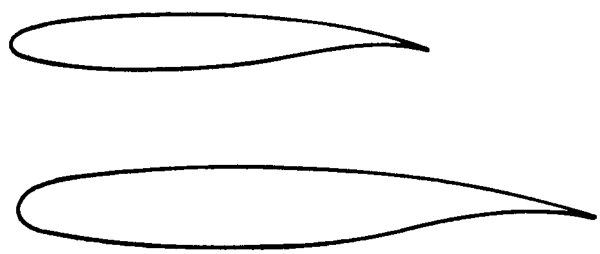


CONVENTIONAL VERSUS SUPERCRITICAL AIRFOILS - GEOMETRIC SHAPE

In 1981 Lockheed conducted a wind tunnel test that compared conventional and supercritical airfoils while holding stiffness, mass, and planform geometric shape constant.

Model Airfoil Profiles for Instrumented Pressure Sections



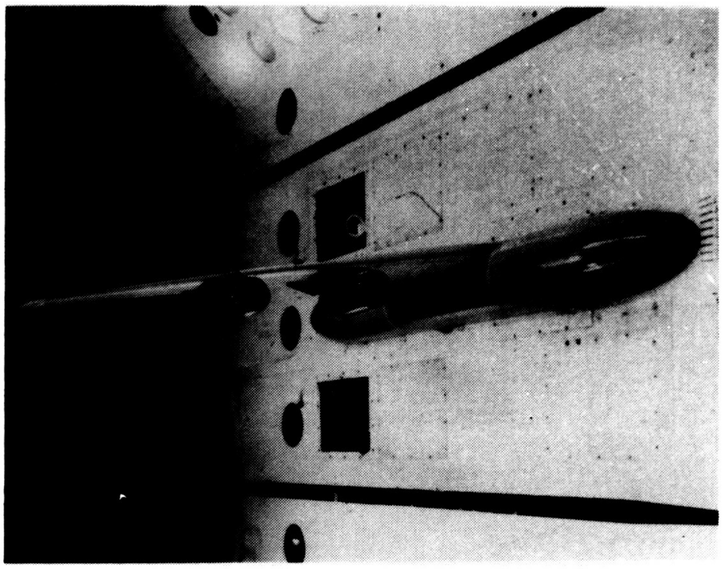


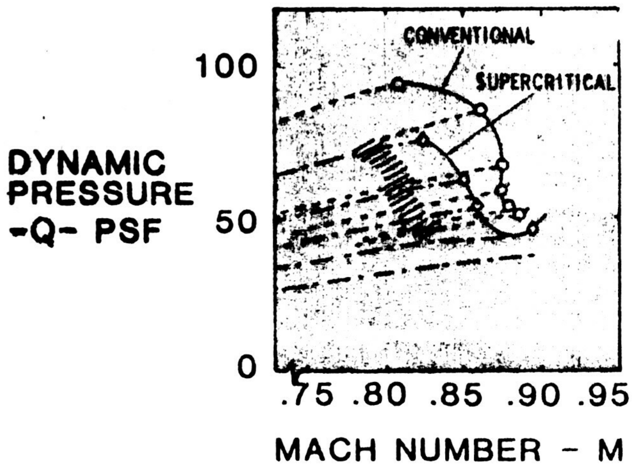
CONVENTIONAL AIRFOIL

SUPERCRITICAL AIRFOIL

CONVENTIONAL VERSUS SUPERCRITICAL AIRFOILS - FLUTTER BOUNDARIES

This test and other tests show that changing from a conventional airfoil shape to a supercritical airfoil shape can greatly reduce the wing's flutter speed. The test also showed that there was a region of low damping within the flight envelope of this wing with supercritical airfoils. This low damping region is shaded in the figure.





PROBLEM

The aerodynamic programs used in flutter analyses do not accurately predict the complex flow around supercritical airfoils in the transonic flow region. This causes the use of long costly wind tunnel tests and empirical weighting factors to modify the analytically predicted flutter speeds. The result can be a stiffer, heavier wing than is needed.

Unsteady transonic aerodynamic programs using Computational Fluid Dynamics (CFD) methods show promise of more accurately predicting transonic flow, but these programs need to be validated before they can be incorporated into a production flutter method.

To validate the programs, analytical predictions must be correlated with steady and unsteady experimental flow data on a flexible, three-dimensional wing. Most of the data available for correlation is from tests on two-dimensional or three-dimensional rigid wings.

In April 1984, Lockheed-Georgia and NASA-Langley conducted a wind tunnel test to obtain all of the types of data needed for CFD program correlation. This included steady state data, forced oscillation data, and oscillatory data during flutter.

* New Technologies Have Lower Flutter Speeds
* Present Analytical Methods Are Not Accurate
* Computational Fluid Dynamics (CFD)
* Verify CFD Programs
* Lack of Test Data for Correlations

TEST OBJECTIVES

There were three main objectives for this test.

a) obtain aerodynamic data during flutter for CFD program correlation
b) obtain a better understanding of supercritical wing flutter
c) evaluate the effects that pylons and engines have on wing unsteady aerodynamics

- OBTAIN CONGRUENT FLUTTER AND AERO DATA FOR ANALYSIS CORRELATION

- OBTAIN BETTER UNDERSTANDING OF SUPERCRITICAL WING FLUTTER

- EVALUATE EFFECTS OF PYLONS AND ENGINES ON WING AERO DATA

MODEL CONFIGURATIONS

Four different model configurations were tested.

a) stiffer spar, bare wing
b) nominal stiffness spar, bare wing
c) nominal stiffness spar with mass simulated engines
d) nominal stiffness spar with aerodynamic simulated engines

The first configuration was used only for obtaining forced response oscillatory data. The other three configurations were used for obtaining both forced response oscillatory data and oscillatory data during flutter.

STIFFER WING (FOUR TIMES NOMINAL STIFFNESS)

- BARE WING

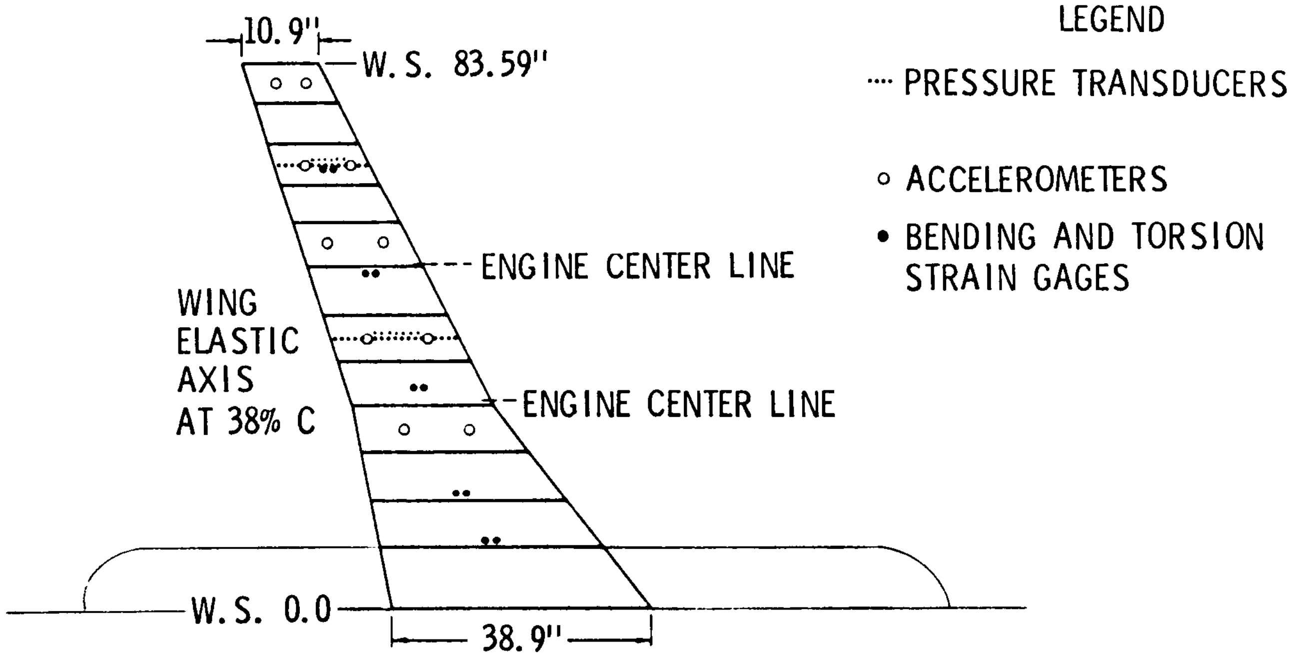
NOMINAL STIFFNESS WING

- BARE WING
- WING PLUS DUMMY NACELLES AND PYLONS
- WING PLUS DUCTED NACELLES AND PYLONS

WING PLANFORM AND INSTRUMENTATION LAYOUT

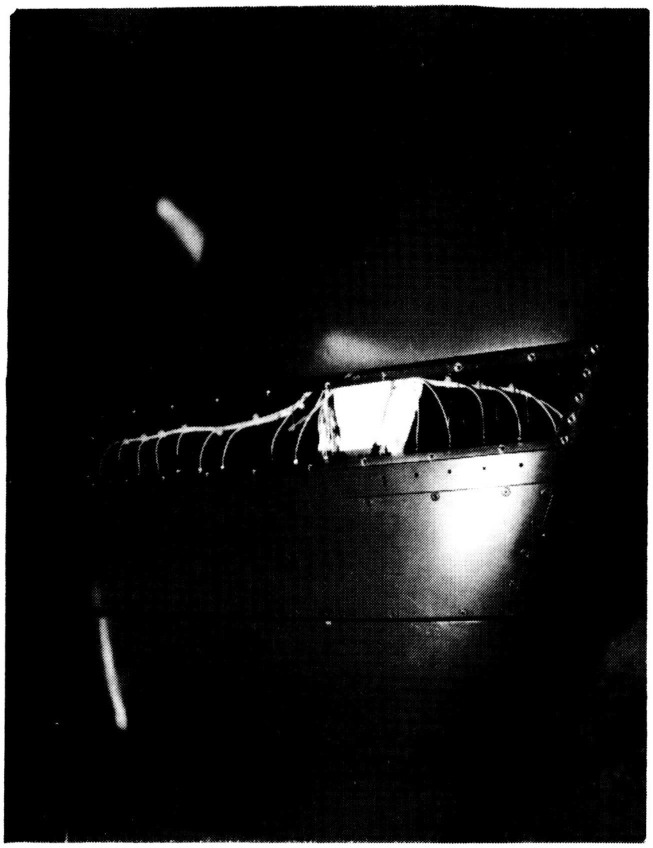
The wing had an aspect ratio of 7.84. It was constructed on a single aluminum spar with a supercritical airfoil. It had eleven mass ballasted sections. Five bending and torsion strain gage bridges and five pairs of accelerometers were distributed along the wing's span to define the steady and unsteady position of the wing. Instrumentation sections were located at 49.6% and 82.1% span. Each instrumentation section contained 17 delta pressure transducers and 7 upper surface pressure transducers from the leading to the trailing edge.

Aeroelastic Model Wing Planform and Instrumentation Layout



PICTURE OF INSTRUMENTATION SECTION

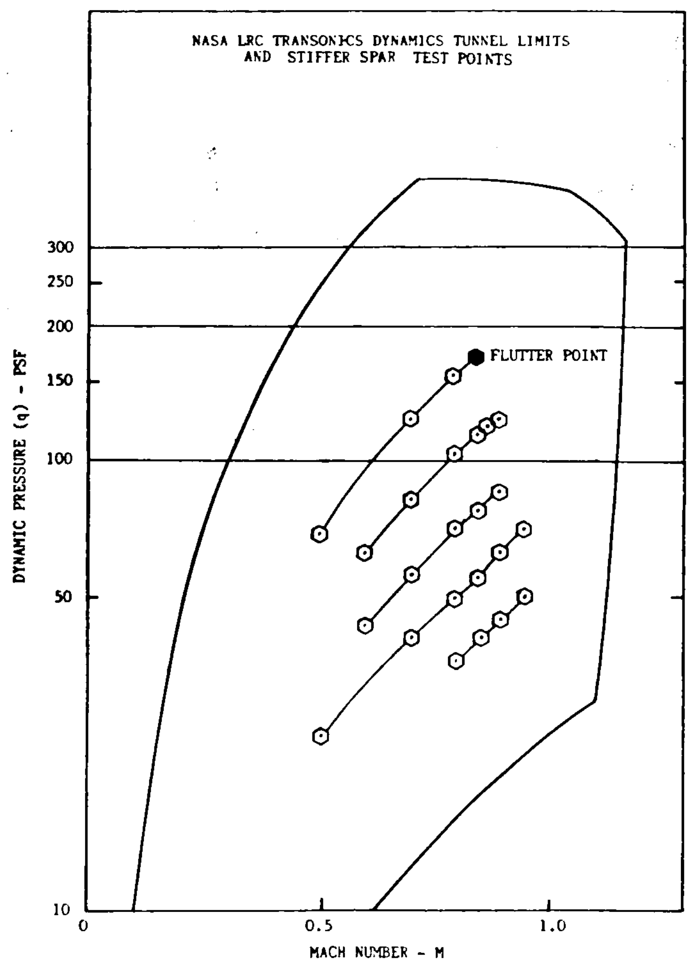
This picture shows an opened up instrumentation section. The holes for the pressure transducers are visible on the wing's surface. Wires from the pressure transducers and the wing's spar are visible inside the model.



STIFFER SPAR TEST POINTS

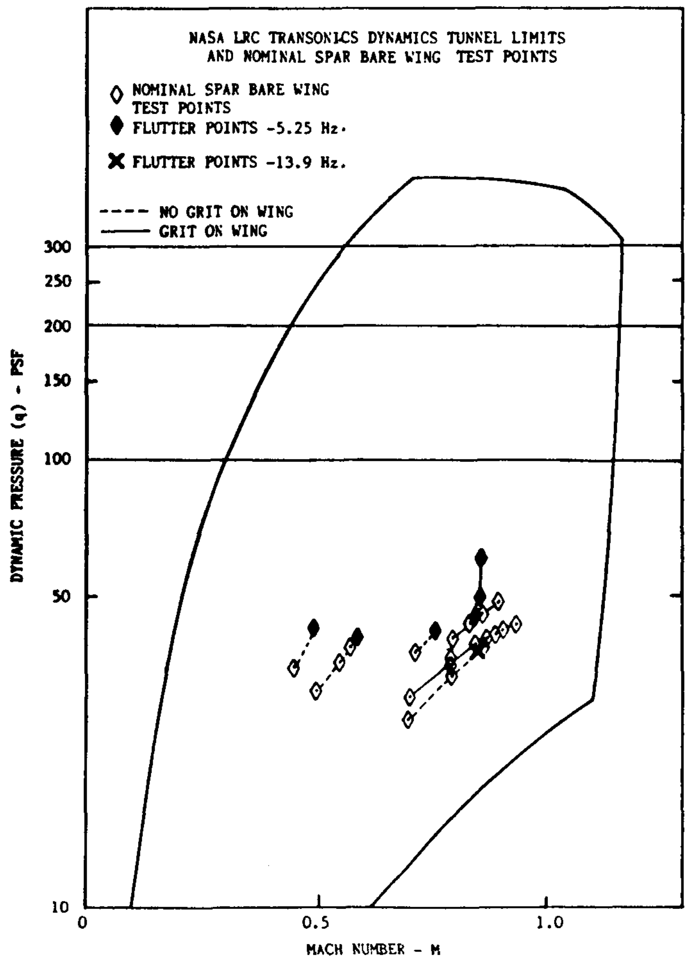
Test points are shown for the stiffer spar, bare wing configuration. The testing procedure is described below.

1. After tunnel was warmed and wind off zero readings were taken, the tunnel speed and density were increased to the desired values.
2. The model was positioned at the desired angle of attack and steady state data was obtained.
3. The wing was oscillated in pitch at 2, 4, 8, and 16 Hertz and unsteady measurements were obtained.
4. The model was positioned at two more steady state angles of attack and oscillated at 2, 4, 8, and 16 Hertz. Steady and unsteady data were measured for each of these conditions.
5. Tunnel speed was increased for testing at other Mach numbers for the same tunnel density.
6. Upon reaching Mach 0.95 or flutter, the tunnel speed was decreased and Freon was pumped in to increase tunnel density to the next desired value.
7. Testing resumed along another constant density line.



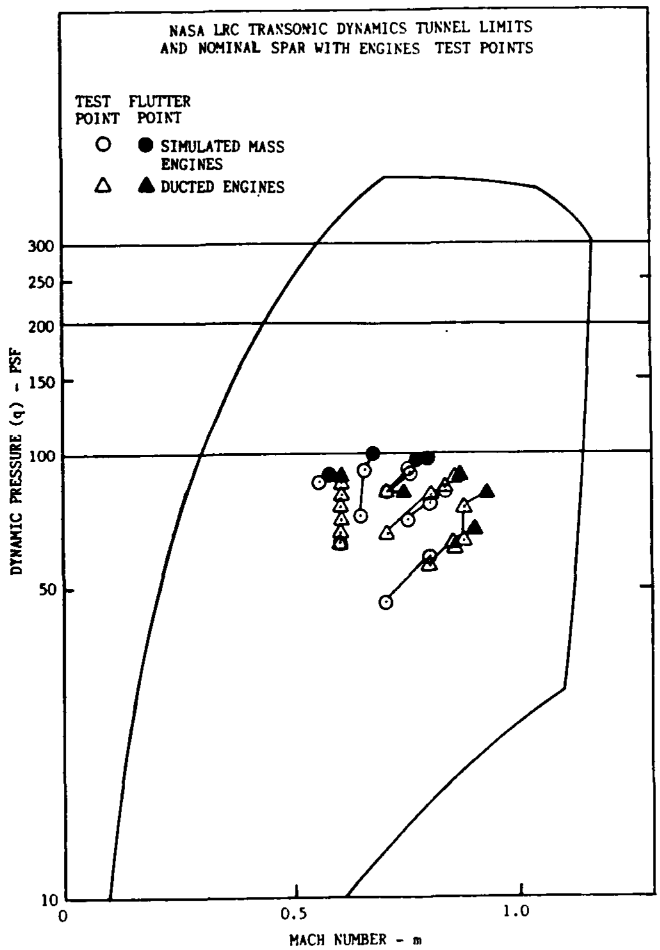
NOMINAL SPAR BARE WING TEST POINTS

Test points are shown for the nominal stiffness spar, bare wing configuration. The flutter boundary for this configuration is also shown. The test procedure was identical to that for the stiff spar, bare wing configuration except forced oscillatory data were measured at fewer than three angles of attack for most test points.



NOMINAL SPAR WITH ENGINES TEST POINTS

Test points are shown for the nominal stiffness spar, with engines configuration. The flutter boundary for this configuration is also shown. The test procedure was identical to that for the nominal stiffness spar, bare wing configuration.



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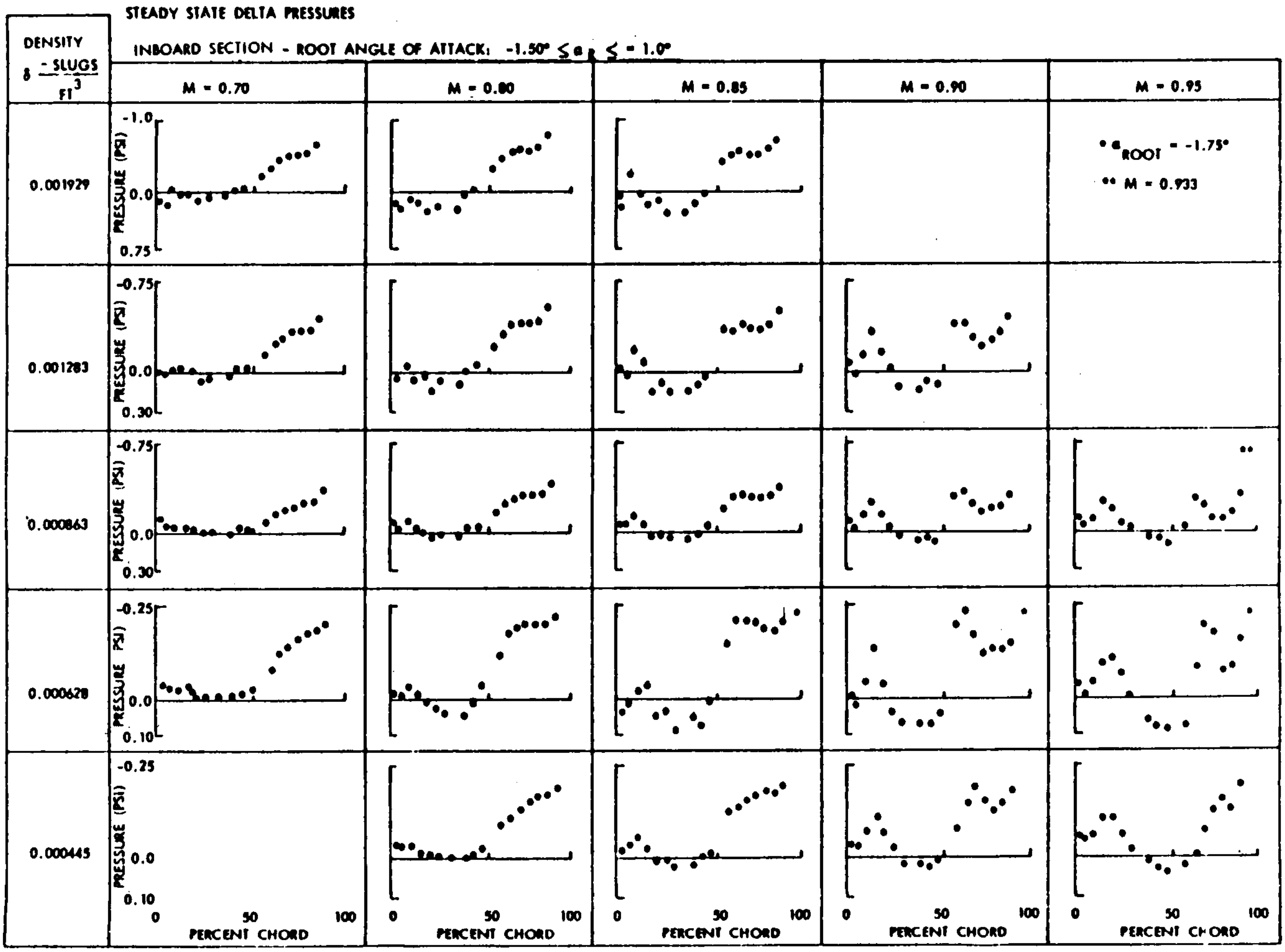
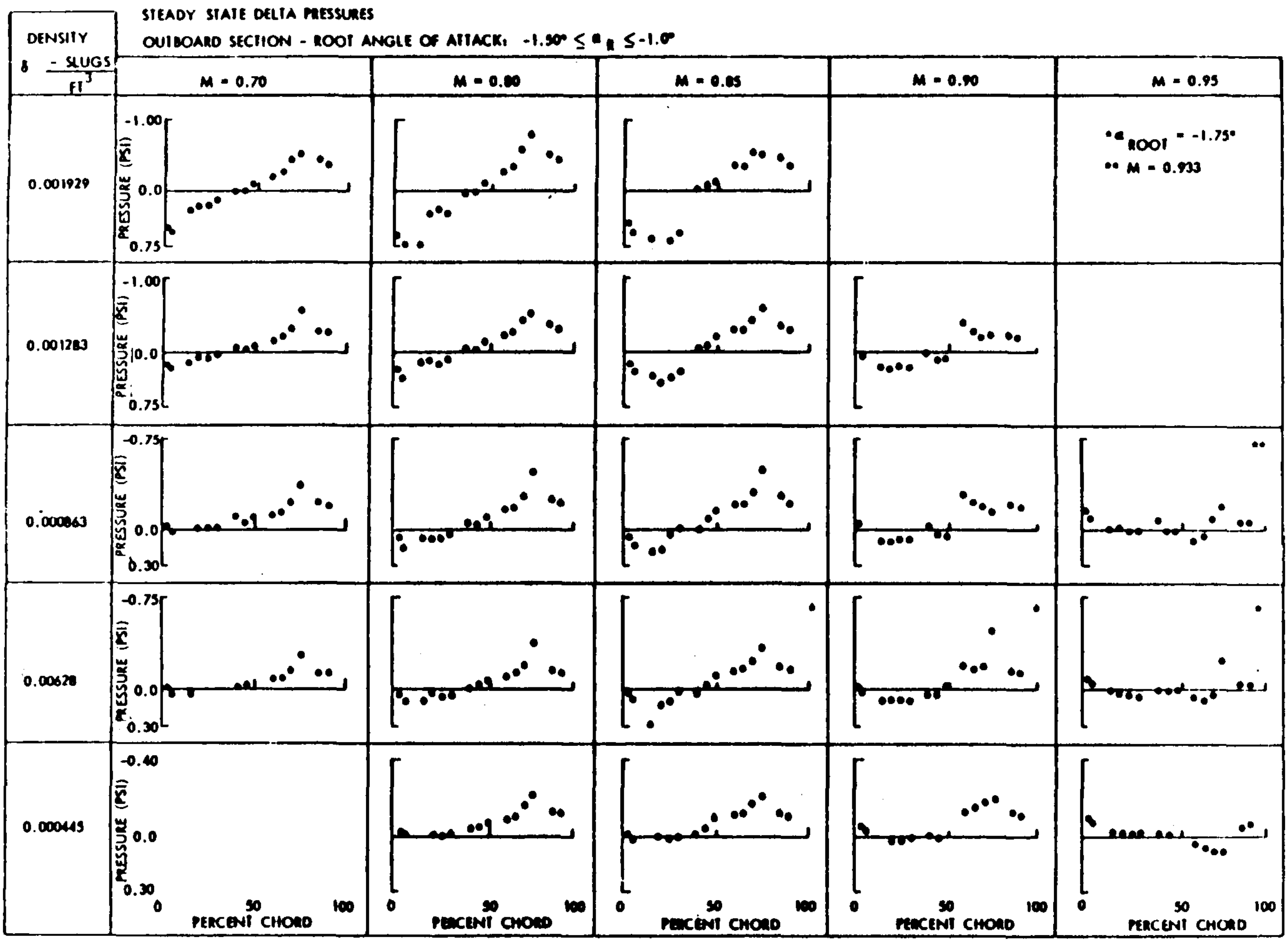
STEADY STATE DELTA PRESSURES - INBOARD SECTION

This is a composite plot showing how the chordwise delta pressure distribution changes with Mach number and tunnel density.



STEADY STATE DELTA PRESSURES - OUTBOARD SECTION

This is a composite plot showing how the chordwise delta pressure distribution changes with Mach number and tunnel density. The differences in chordwise delta pressure distributions between the inboard and outboard sections is due to the difference in local angle of attack caused by the jig twist and the flexibility of the wing.



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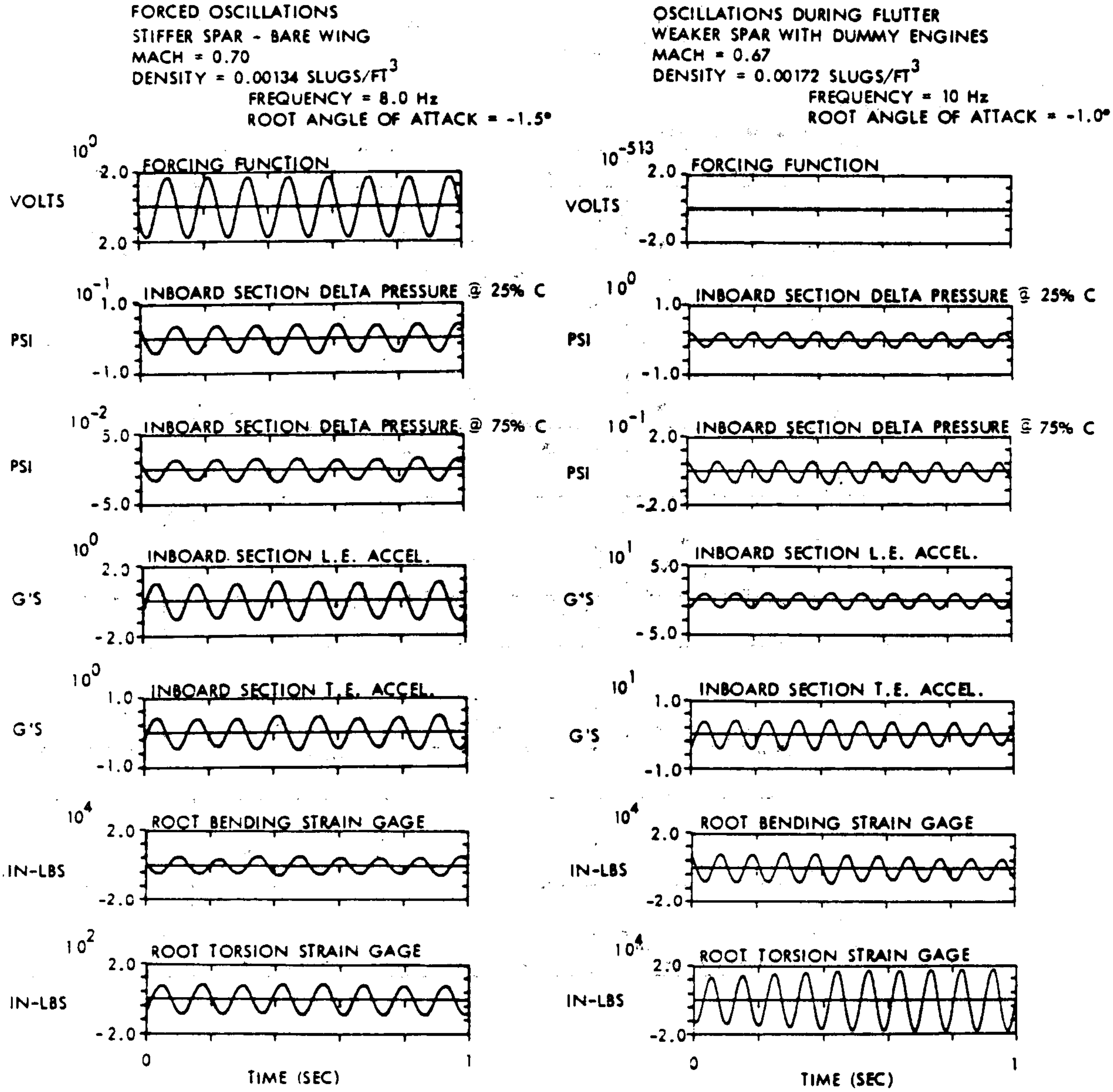
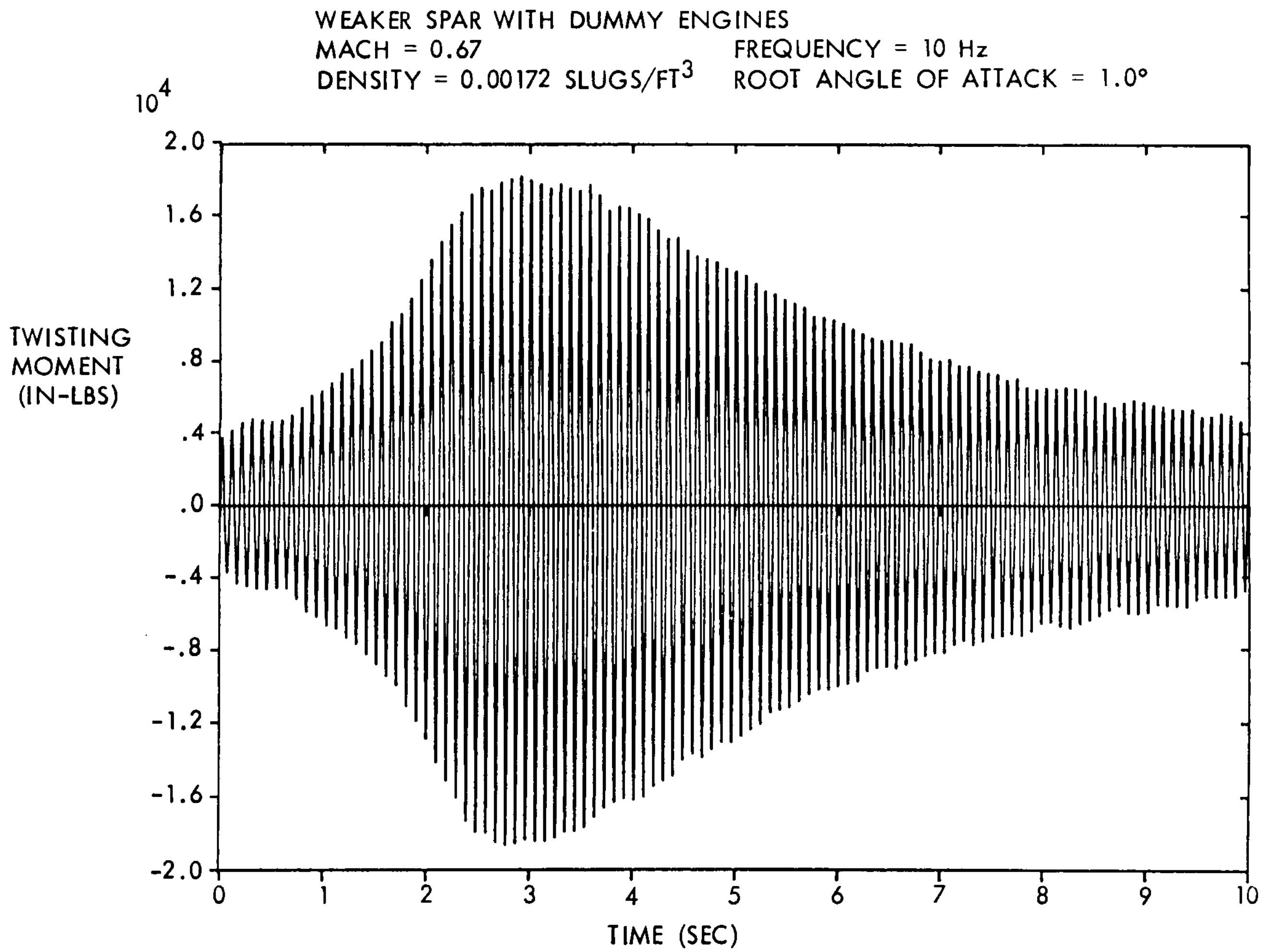
TIME HISTORY PLOTS

This figure shows time history traces for a sample of data channels for both a forced oscillation case and for oscillations during flutter.



ROOT TORSION STRAIN GAGE - TIME HISTORY DURING FLUTTER

This figure shows a time history plot of the root torsion strain gage during a flutter case. During the first $2\frac{1}{2}$ seconds of this plot the model's deflection is increasing from flutter onset. After $2\frac{1}{2}$ seconds, the tunnel velocity was decreased by about 10% to keep the model from breaking up. The rest of the plot shows the model's response gradually decreasing at the lower tunnel speed.



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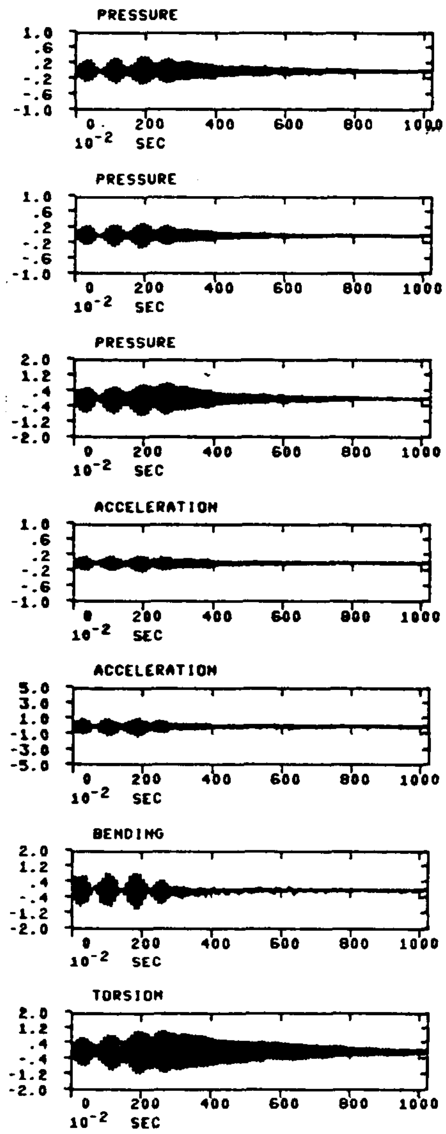
TIME HISTORIES - BEATING FLUTTER

Aerodynamic data was also measured while the model was beating in and out of flutter. This figure shows a sample of data channels during this beating phenomenon.



Time Histories; Nominal Spar Self-Sustained

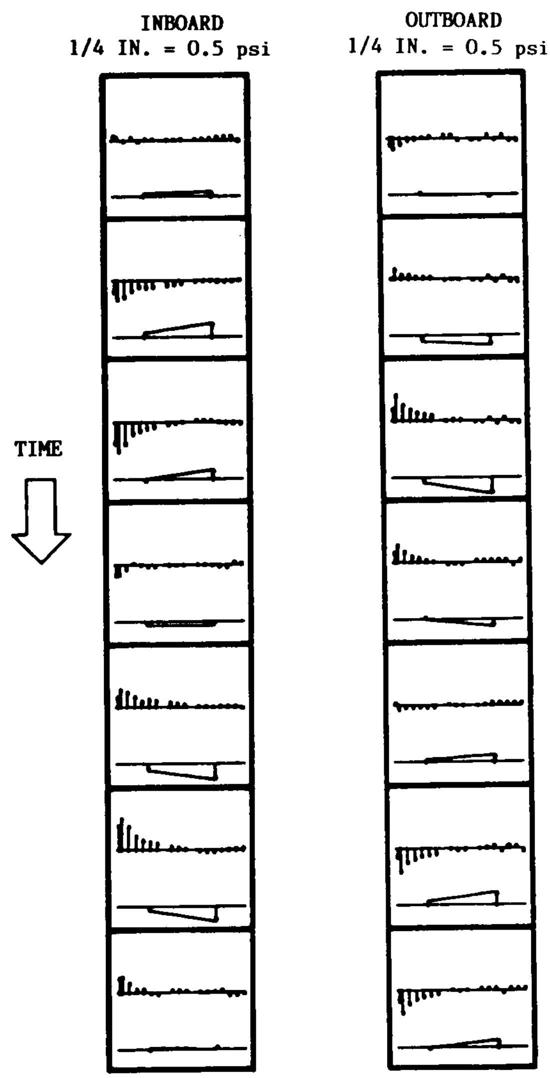
Oscillations 10.4 Hz. ; M = 0.79; q = 97.3 psf

TIME HISTORY CHORDWISE DELTA PRESSURE OSCILLATIONS DURING FLUTTER

Moving from the top of this figure to the bottom, one cycle of forced response data is shown for both the inboard and the outboard sections. Nine instantaneous "snapshots" are shown to depict how the chordwise delta pressure and airfoil position change with time. In each "snapshot" the top line is a bargraph of the delta pressure measurements (the leading edge is to the left and the trailing edge is to the right). The lower line in each "snapshot" depicts the unsteady airfoil position.

FREQUENCY = 10 Hz DENSITY = 0.00172 SLUGS/FT.^{3}

ROOT ANGLE OF ATTACK = +1.0° MACH = 0.67



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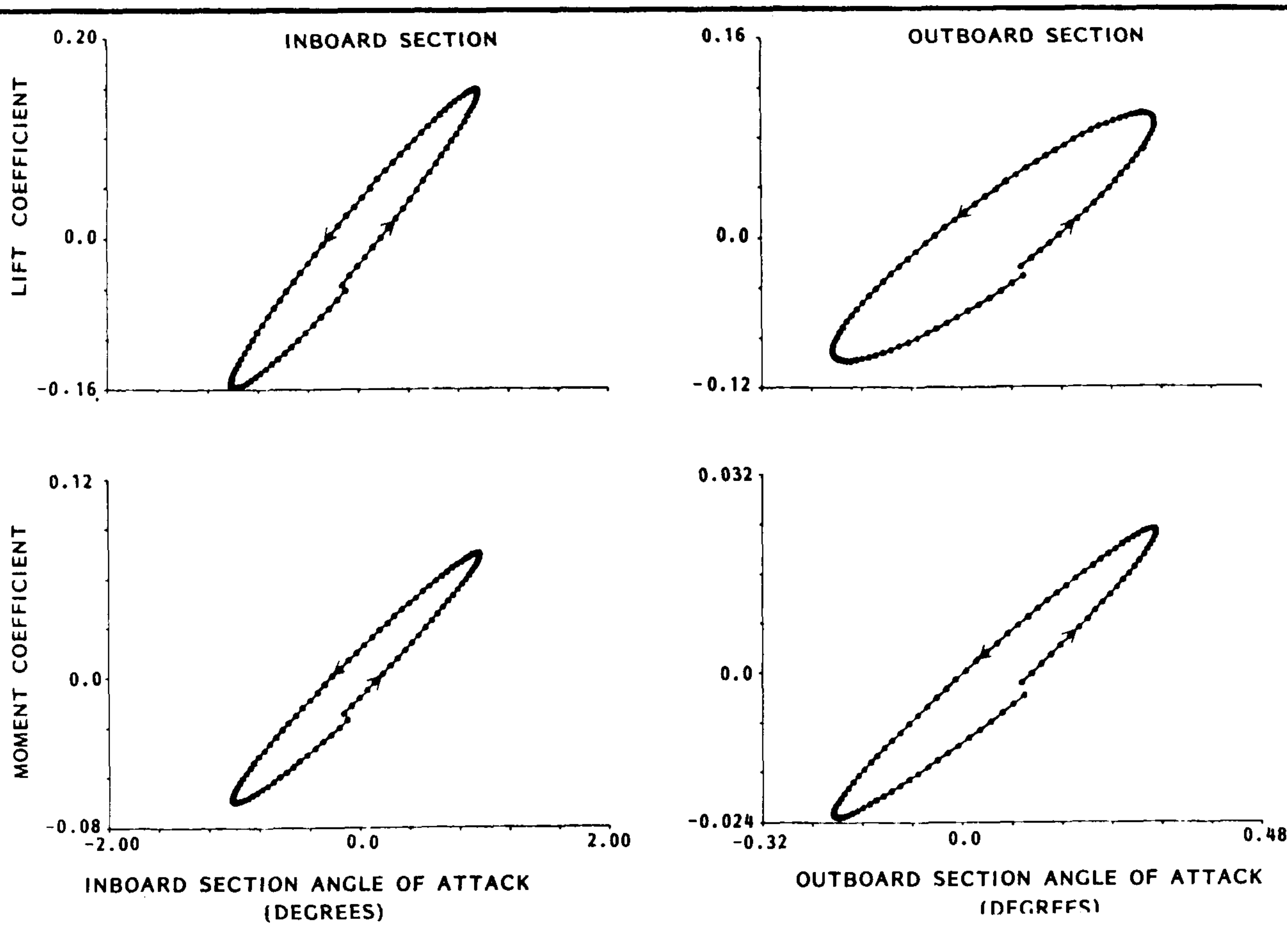
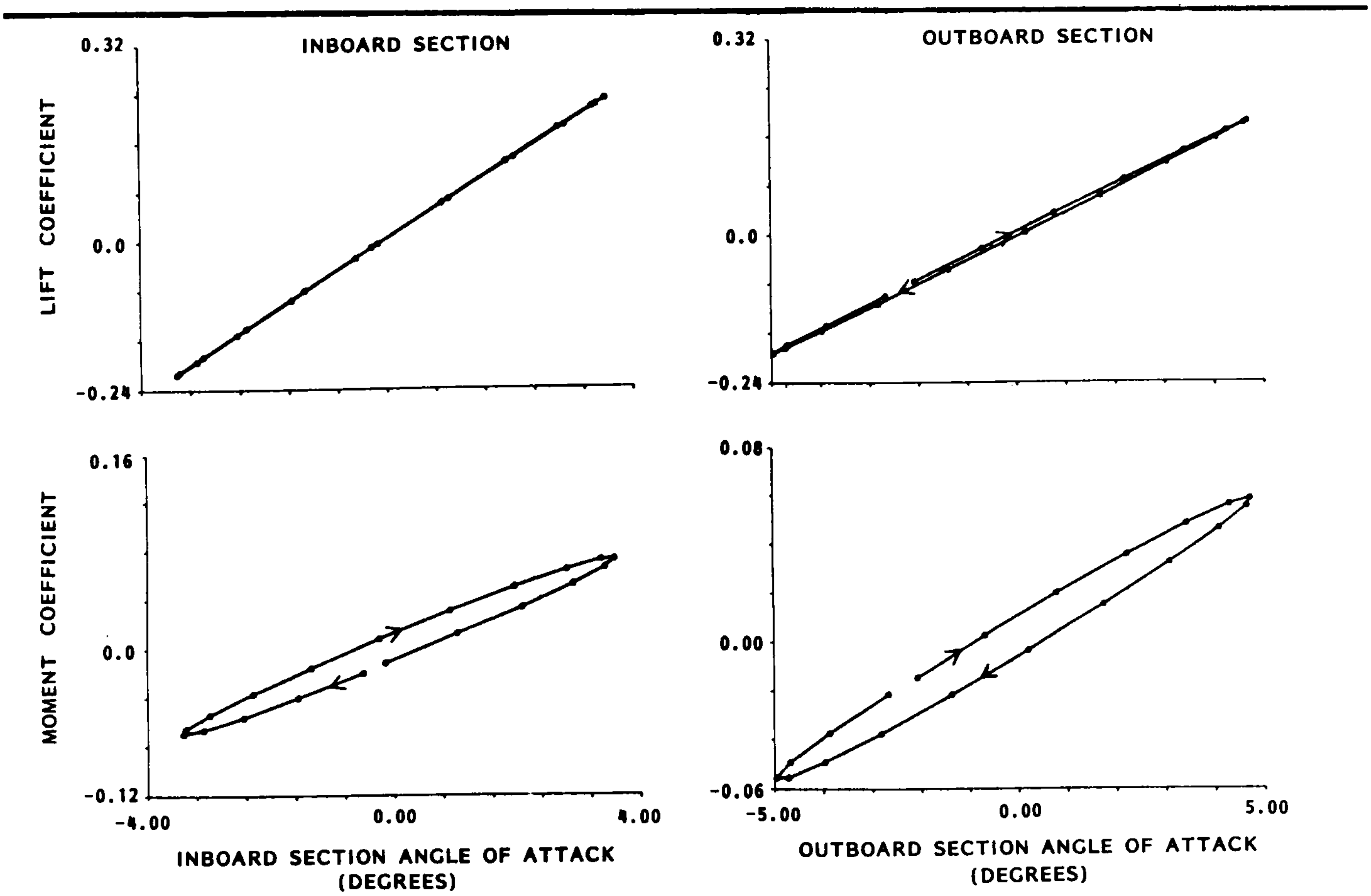
REPRESENTATIVE FORCED RESPONSE AERODYNAMIC COEFFICIENTS

From the instantaneous chordwise delta pressure distribution, the lift and the lift and moment coefficients were calculated. These "instantaneous" coefficients were plotted in this figure versus the section's "instantaneous" angle of attack. For the forced response case, the hysteresis moves in a counter-clockwise rotation indicating that energy is being put into the airstream by the airfoil.



REPRESENTATIVE AERODYNAMIC COEFFICIENTS DURING FLUTTER

This is the same type of data from oscillations during flutter. Note that the hysteresis is moving in a clockwise rotation indicating that energy is being extracted from the airstream by the airfoil.



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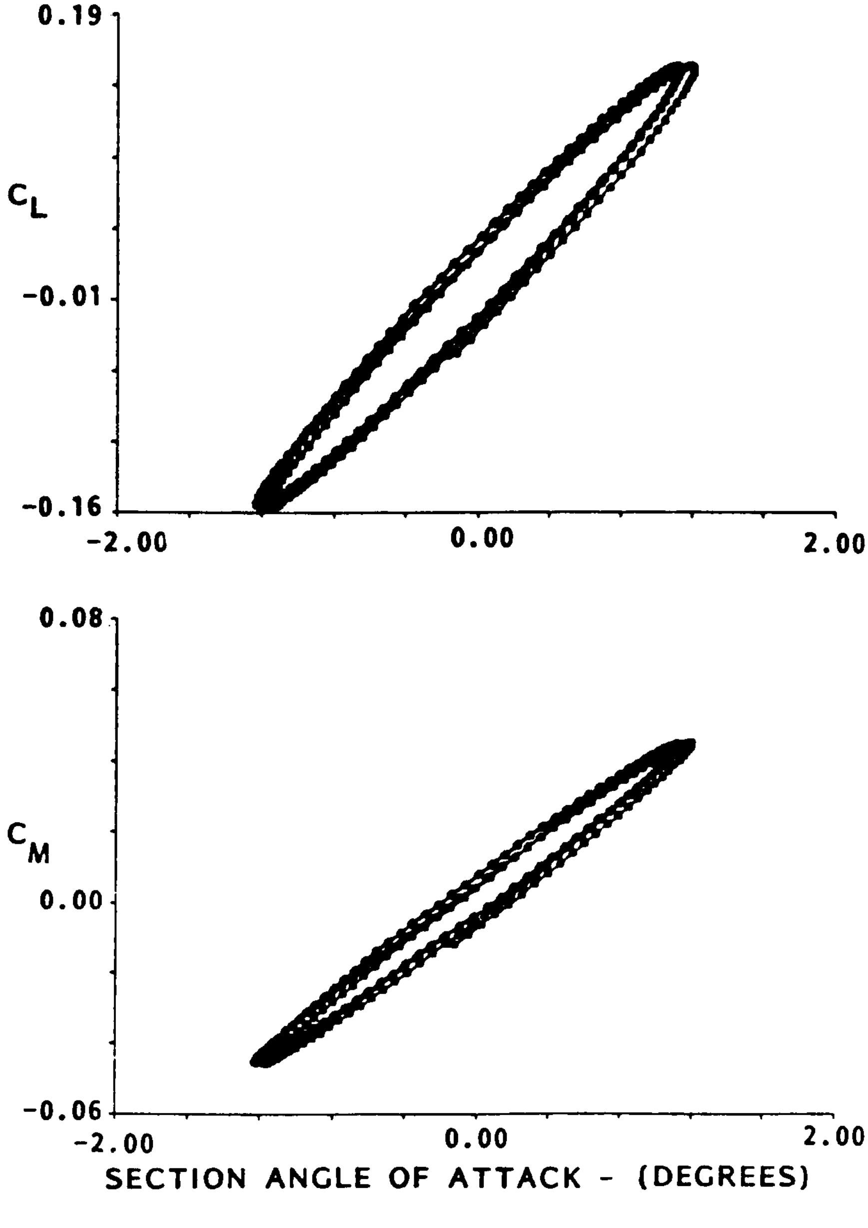
REPRESENTATIVE MULTICYCLE AERODYNAMIC DATA

Three cycles of data have been plotted to show the repeatability of the data. The case shown is during forced oscillations. During a divergent flutter case, the model's amplitude is building so the plotted data would also increase in magnitude.

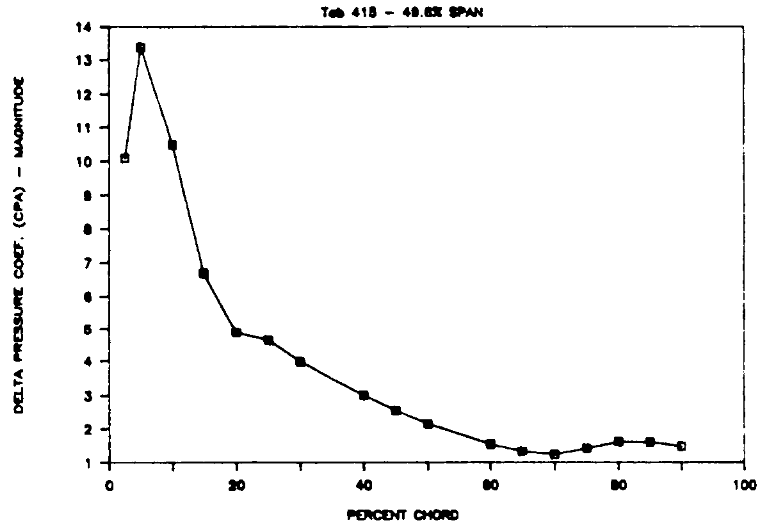


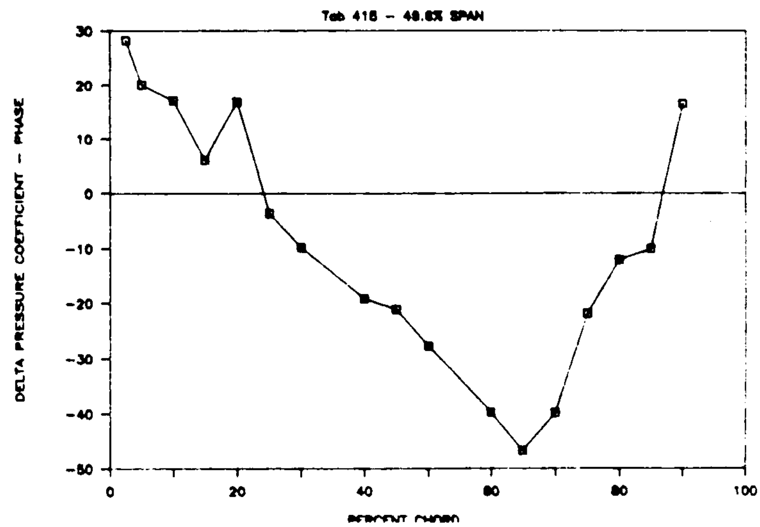
CHORDWISE DELTA PRESSURE COEFFICIENTS - 49.6% SPAN

Unsteady chordwise delta pressures are presented in magnitude/phase plots for representative measurements during flutter.

$$C_{dp} = dp_{max}/(Q*alpha_{max})$$

Mach = 0.670 Q = 99.000
Root Alpha = 1.000 Inboard Section Alpha = 4.809





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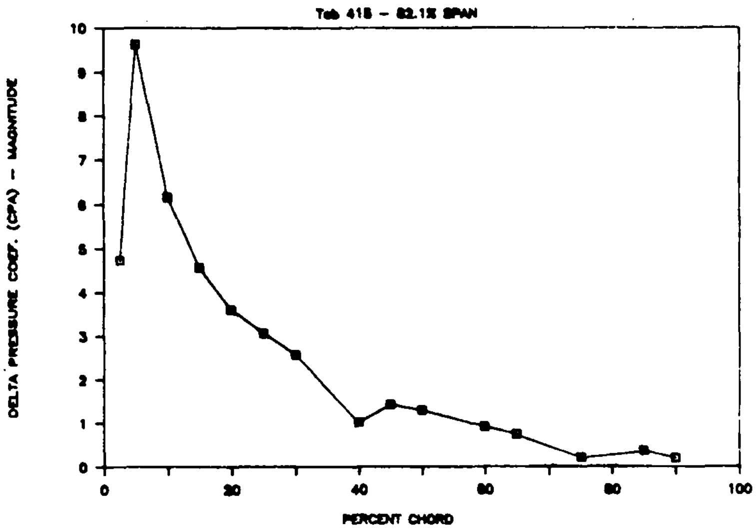
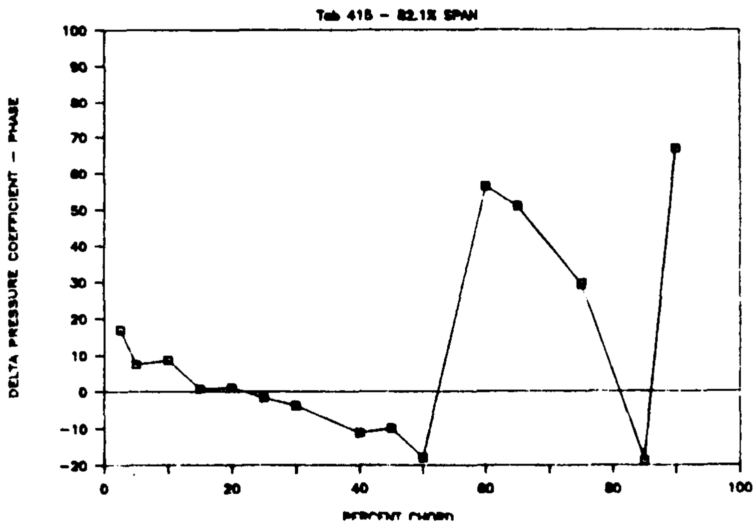
CHORDWISE DELTA PRESSURE COEFFICIENTS - 82.1% SPAN

Unsteady chordwise delta pressures are presented in magnitude/phase plots for representative measurements during flutter.

$$C_{dp} = dp_{max}/(Q*alpha_{max})$$

Mach = 0.670 Q = 99.000
Root Alpha = 1.000 Outboard Section Alpha = 1.1 45





CHORDWISE DELTA PRESSURE COEFFICIENTS

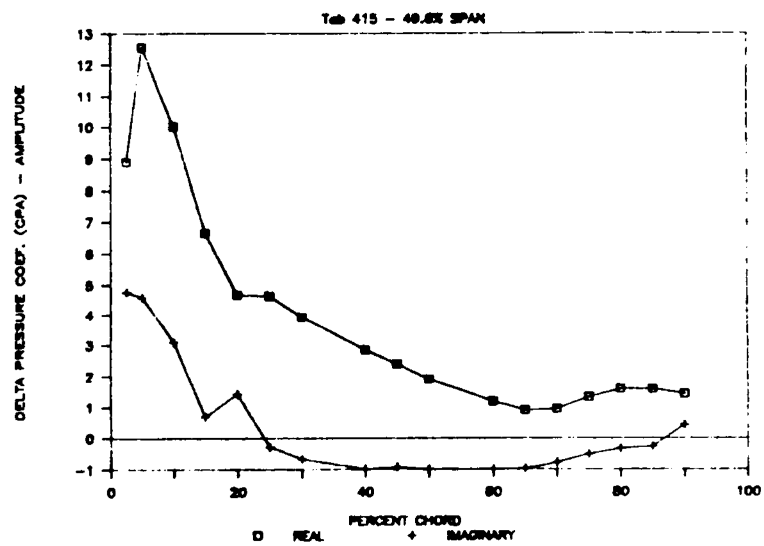
Unsteady chordwise delta pressures are presented in real/imaginary plots for representative measurements during flutter.

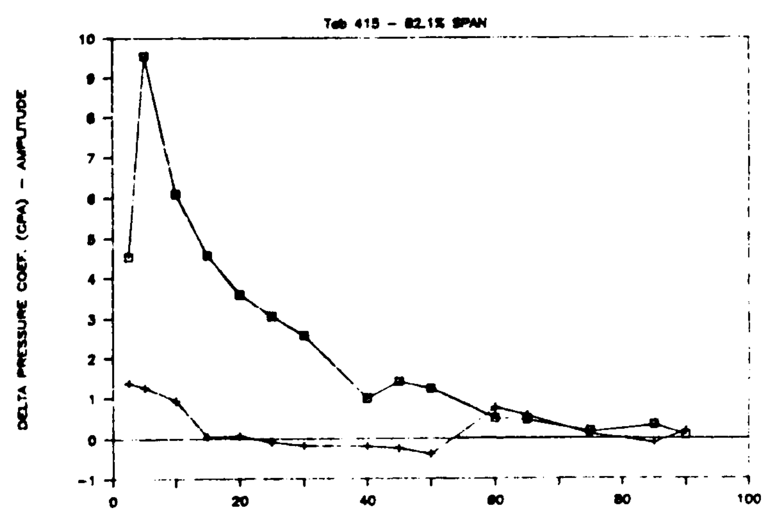
$$C_{dp} = dp_{max}/(Q*alpha_{max})$$

Mach = 0.670 Q = 99.000

Root Alpha = 1.000 Inboard Section Alpha = 4.809

Outboard Section Alpha = 6.657





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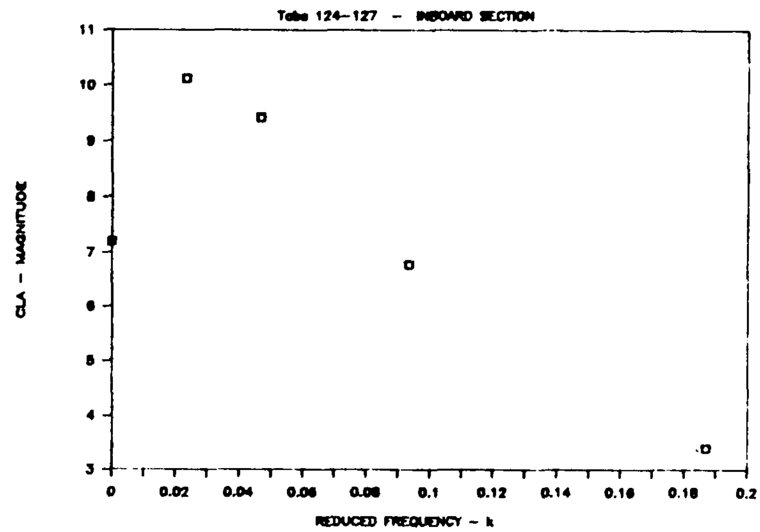
UNSTEADY LIFT COEFFICIENT - 49.6% SPAN

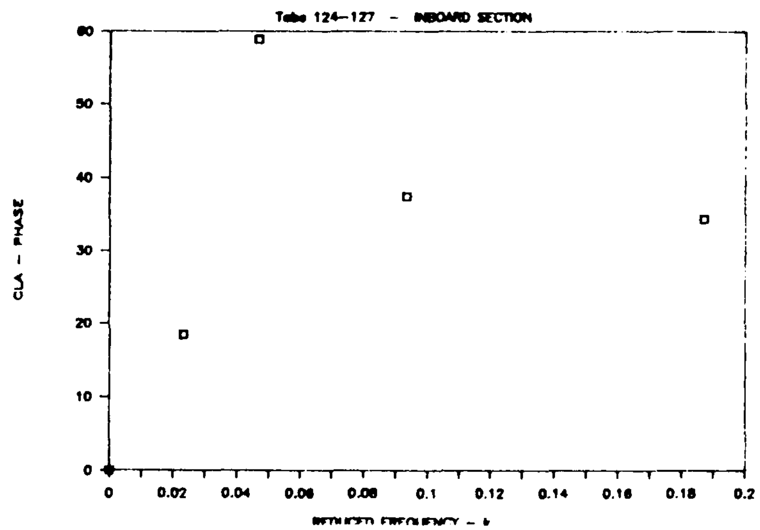
$C_{\ell\alpha}$'s are plotted for steady state, 2, 4, 8, & 16 Hertz at α_{root}=-1.5 degrees. Magnitude/phase plots are shown for measurements at 49.6% span. Plots are made versus reduced frequency -k.

$$C_{\ell\alpha} = C_{\ell_{max}} / \alpha_{max}$$

$$k = b\omega/V = \frac{(c/2)*2\pi f}{\sqrt{2Q/\rho_\infty}}$$

Mach = 0.859 Q = 40.68
Root Alpha = -1.500 Inboard Section Alpha = -0.801





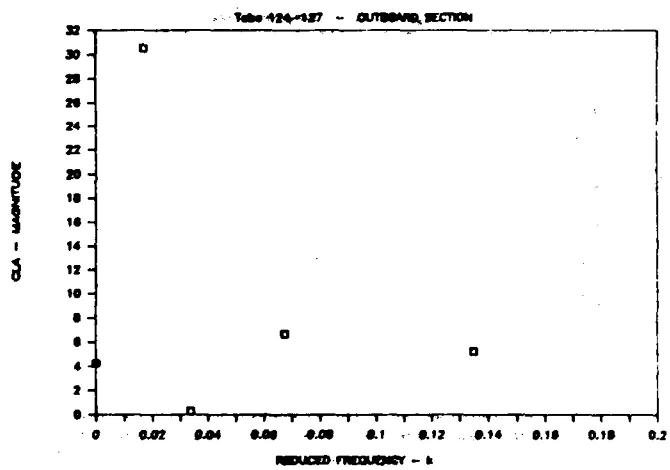
UNSTEADY LIFT COEFFICIENTS -82.1% SPAN

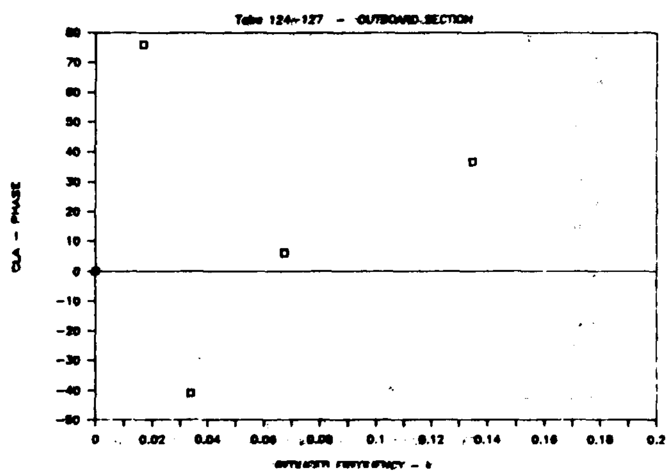
C_{ℓ_α}'s are plotted for steady state, 2, 4, 8, & 16 Hertz at α_{root}=-1.5 degrees. Magnitude/phase plots are shown for measurements at 82.1% span. Plots are made versus reduced frequency -k.

$$C_{\ell_\alpha} = C_{\ell_{max}} / \alpha_{max}$$

$$k = b\omega/V = \frac{(c/2)*2\pi f}{\sqrt{2Q/\rho}}$$

Mach = 0.859 Q = 40.68
Root Alpha = -1.500 Outboard Section Alpha = -0.357





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UNSTEADY LIFT COEFFICIENTS

C_{ℓ_α}'s are plotted for steady state, 2, 4, 8, & 16 Hertz at α_{root}=-1.5 degrees. Real/imaginary plots are shown for measurements at 49.6% and 82.1% spans. Plots are made versus reduced frequency -k.

$$C_{\ell_\alpha} = C_{\ell_{max}} / \alpha_{max}$$

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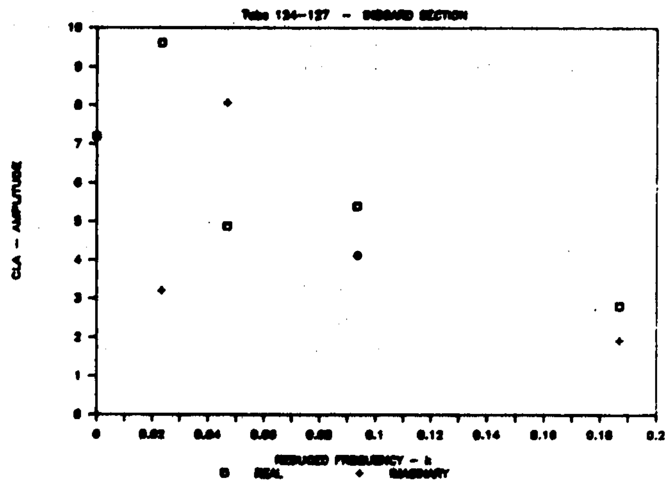
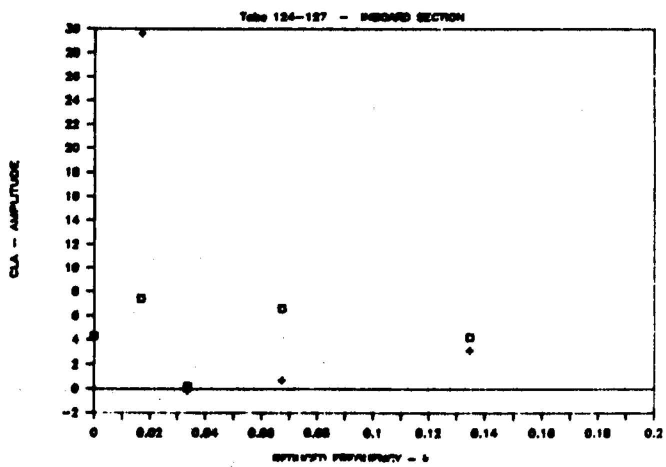
Outboard Section Alpha = -0.357





SUMMARY

1. Present flutter analysis methods do not accurately predict the flutter speeds in the transonic flow region for wings with supercritical airfoils.

2. Aerodynamic programs using CFD methods are being developed, but these programs need to be verified before they can be used with confidence.

3. A wind tunnel test was performed to obtain all types of data necessary for correlating with CFD programs to validate them for use on high aspect ratio wings. The data include steady state and unsteady aerodynamic measurements on a nominal stiffness wing and a wing four times that stiffness. There is data during forced oscillations and during flutter at several angles-of-attack, Mach numbers, and tunnel densities.

4. The test data is being compiled and will be published in a NASA report. Data will also be available through NASA on magnetic tape.

5. The data is intended to be used for correlating with and verifying CFD aerodynamic programs.

- **IMPROVED TRANSONIC FLUTTER ANALYSES NEEDED**
- **COMPUTATIONAL FLUID DYNAMIC CODES**
- **PRESSURE / FLUTTER MODEL TEST CONDUCTED**
- **COMPILATION OF TEST DATA**
- **CORRELATION OF TEST DATA WITH CFD CODES**